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Original line drawings or glossy black-and-white prints of each figure must be attached to original.

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B. A. Cook
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Title of Summary Behavior of a Failed Fuel Rod During Film Boiling Operation

This is to acknowledge receipt of your summary. Please use the log number above in future correspondence.

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Thank you for submitting this summary.

Sincerely,

Weston M. Stacey, Jr.
ANS Technical Program Chairman
1979 Annual Meeting

EG&G Idaho, Inc.

P. O. Box 1625
Idaho Falls, Idaho 83401

January 26, 1979

Mr. Weston M. Stacey, Jr.
ANS Technical Program Chairman
American Nuclear Society
555 North Kensington Avenue
Lagrange Park, IL 60525

Attention: Ms. Ruth Farmakes

TRANSMITTAL OF PAPER FOR ANS 1979 ANNUAL MEETING - BAC-1-79

Dear Mr. Stacey:

The summary titled "Behavior of a Failed Fuel Rod During Film Boiling Operation" is enclosed with this letter. We are submitting this summary for presentation at the ANS 1979 Annual Meeting, and publication in the Transactions of the American Nuclear Society. Publication should be withheld pending patent clearances, which are being processed.

Correspondence concerning this summary should be addressed to B. A. Cook, 208-526-9284 (FTS 583-9284).

Very truly yours,

Beverly A Cook

B. A. Cook

de

Enclosure:
As stated

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CONF-790602--3

BEHAVIOR OF A FAILED FUEL ROD DURING FILM BOILING OPERATION
(PCM-1 Test in the PBF)

B. A. Cook, R. R. Hobbins*, and D. T. Sparks

A single rod power-coolant-mismatch test (Test PCM-1) was conducted in the Power Burst Facility to evaluate the behavior of a pressurized water reactor (PWR)-type fuel rod subjected to film boiling operation at high power for a time exceeding that resulting in rod failure. The mechanisms of rod failure, the test rod response following failure, and the consequences of operation with a large molten fuel radius following fuel rod failure were investigated through destructive and nondestructive examination.

The Test PCM-1 rod was of a nominal 15 x 15 PWR design with an enrichment of 20 wt% ^{235}U and a fuel stack length of 0.91 m. The rod was backfilled to 2.45 MPa with 78% Helium and Argon and was positioned within a circular zircaloy flow shroud with a rod-to-shroud diametral clearance of 5.6mm. The fuel rod was instrumented for measurement of plenum gas pressure, and cladding elongation and temperature.

The Test PCM-1 film boiling transient was initiated by ramping the fuel rod peak power from 39 kW/m to 69 kW/m at a rate of 33 kW/m per minute. Constant coolant conditions (pressure, coolant inlet temperature, and shroud coolant flowrate) were maintained during the power transient. Approximately 280 seconds after the start of the power ramp, the test rod peak power was adjusted to 78 kW/m and maintained at that level for the remainder of the film boiling operation. The Test PCM-1 rod attained film boiling on the first power ramp and was held in film boiling for about 900 seconds. The rod achieved a maximum stable film boiling length over 70% (from 0.21 to 0.85 m above the bottom of the fuel stack) of the test fuel rod.

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* Member, American Nuclear Society

E&B

Significant breakup of the fuel rod occurred during testing, as is shown in Figure 1. The initial failure mechanism was probably cladding embrittlement. At the average cladding temperature of 1800 K, embrittlement of the cladding by oxidation would have been expected when the β phase in the zircaloy was entirely consumed (24% ECR). This criterion was met at 580 seconds. Instrumentation gave indications of initial rod failure at 520 seconds. The initial failure location could not be determined due to the extensive chemical and mechanical interaction of the fuel rod components.

Additional rod fragmentation occurred at shutdown. Twenty-four percent of the fuel stack broke into pieces less than 76 μm in size and were swept from the flow shroud by the coolant flow. However, several unclad sections of the fuel stack, a maximum of 3 cm long, remained intact. Examination revealed the unclad fuel sections to have operated for some period of time in film boiling.

Extensive oxidation of the cladding served to insulate the fuel pellets and raise the fuel temperatures. The fuel rod operated with up to 85% of the pellet radius molten, however, no molten fuel was found solidified on the outside of the fuel rod. Operation of a failed rod with extensive fuel melting (over at least 0.37 m of the 0.91 m fuel stack) did not produce a pressure pulse in the coolant or other significant effects from molten fuel-coolant interaction.

Evidence of cladding melting was observed over about 0.1 m of the fuel rod. The molten cladding was contained in an oxide shell in some locations long enough for the molten zircaloy to absorb oxygen and transform to solid ZrO_2. The cladding was observed to be embrittled between the 0.30- and 0.68-m elevations. However, in this region, sections of fuel rod with completely embrittled cladding (all ZrO_2 or ZrO_2 and oxygen-stabilized alpha zircaloy) remained intact. In some locations the oxidized cladding was bonded to the fuel.

Chemical changes occurred in the UO_2 fuel as a result of fuel exposure to steam for an extended period of time. Evidence of U_4O_9 was found at several locations. The higher oxygen content of the fuel tended to accelerate grain growth and reduce the fuel melting temperature. The thermal conductivity of the fuel was also decreased. The compositional changes and unusual porosity distributions in the fuel did not appear to significantly affect fuel rod integrity during extended film boiling operation.

Test PCM-1 was performed at more severe conditions than are postulated to occur in a power reactor. The fuel rod operated in film boiling for 520 seconds before failure due to cladding embrittlement occurred. Additional rod fragmentation occurred at test shutdown, but a significant portion of the fuel rod, including sections with embrittled cladding and unclad fuel rod sections, remained intact. Cladding oxidation and embrittlement rather than fuel oxidation and melting appeared to contribute most significantly to fuel rod fragmentation during extended film boiling operation.

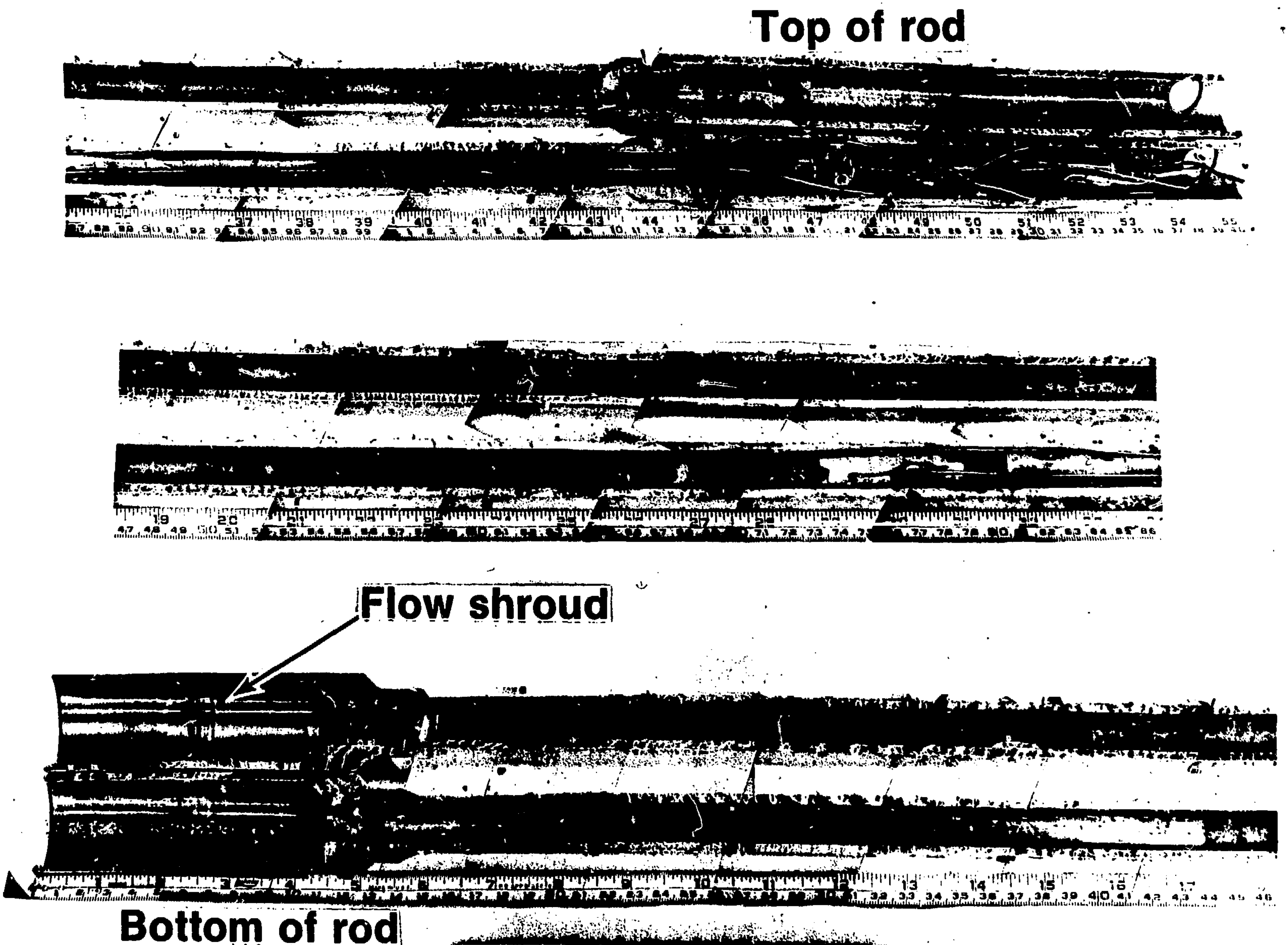

Fig. 1 Overall view of PCM-1 fuel rod in flow shroud.

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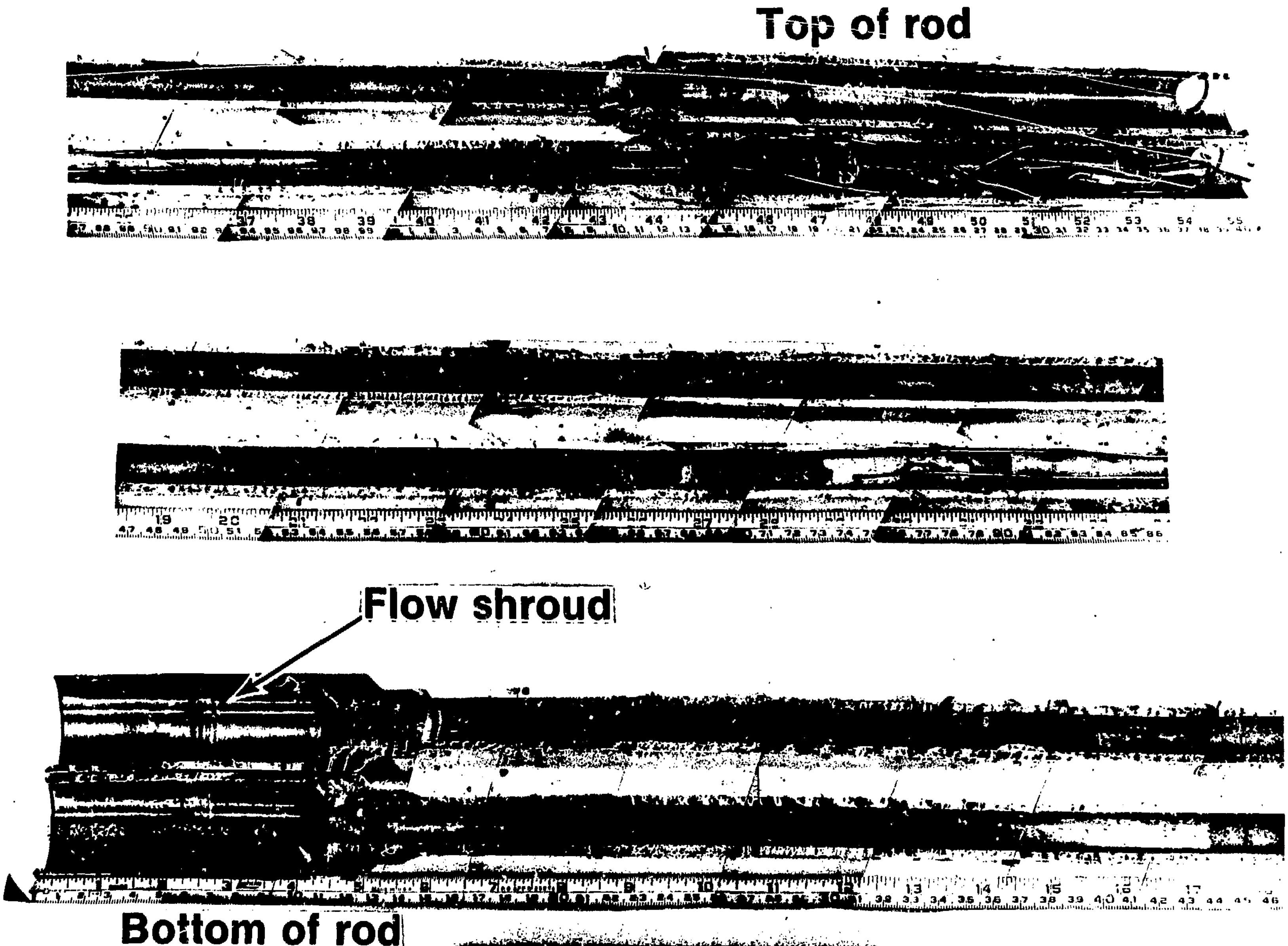

Fig. 1 Overall view of PCM-1 fuel rod in flow shroud.